New Methods in Molecular Spectroscopy:
Cologne Center for THz Spectroscopy

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The *Cologne Center for THz Spectroscopy* invites guests to use a wide variety of instruments to obtain spectra from the far-infrared to the mid-infrared region. Spectra of complex organic molecules (COMs) are recorded in several conventional absorption spectrometers in order to identify them in observations of the ALMA, Herschel and SOFIA telescopes. Driving questions in this area of research are, e.g., up to which molecular complexity do these species grow in the interstellar environment and how can they be formed under the prevailing low pressure and temperature conditions.

Apart from these traditional spectroscopy tools, new instruments are built in the Cologne laboratories to improve the sensitivity, frequency coverage and spectral resolution, in particular to allow the study of radicals and ions which shall be found in future observations. We present a 75-110 GHz emission spectrometer which is operated at room temperature. An immediate bandwidth of 2.5 GHz is recorded with this instrument at a noise temperature of only several hundred Kelvin. Apart from its high sensitivity new features will be discussed. A chirped pulse spectrometer has been constructed not only to record broad band spectra but in particular to determine rate coefficients for inelastic and reactive collisions.

The method of light induced reactions (LIR) has been developed over the last 20 years in our group in order to record spectra of mass selected, cold molecular ions which are stored in ion traps. Compared to traditional absorption spectroscopy in discharge cells the sensitivity of our devices is increased by many orders of magnitude. The spectral resolution is high enough to predict THz spectra at sub-MHz accuracy which is sufficient to identify those ions in astronomical observations [1]. Changing the population of the rotational states and interrogating them by LIR in double resonance experiments leads to predictions of THz transition frequencies at the 10^{-9} level [2], which challenge observations [3]. The ion trap instrument FELion allows to record spectra of cold ions over a range of 250 – 3200 cm^{-1}. This approach allows the identification of isomers and conformers of the molecular species selected by mass spectrometry. Moreover, identifying the vibrational bands of more complex molecular ions challenges quantum chemical predictions [4] and is used as a basis for high-resolution studies in order to find those molecules in space [5].

References

[1] S. Brünken, O. Sipilä, E.T. Chambers, J. Harju, P. Caselli, O. Asvany, C.E. Honingh, T. Kamiński, K.M. Menten, J. Stutzki, and S. Schlemmer, *An age of at least 1 Myr for a dense cloud core forming Sun-like stars*, Nature, 516, 219–221 (2014).
[2] P. Jusko, O. Asvany, A.-C. Wallerstein, S. Brünken, S. Schlemmer, *Two photon rotational action spectroscopy of cold OH^- at 1 ppb accuracy*, Phys.Rev.Lett. **112** (2014) 253005.
[3] S. Brünken, L. Kluge, A. Stoffels, O. Asvany, and S. Schlemmer, *Laboratory Rotational Spectrum of l-C_3H^+ and Conformation of its Astronomical Detection*, ApJ **783** (2014) L4.
[4] O. Asvany, P. Kumar, I. Hegemann, B. Redlich, S. Schlemmer and D. Marx, Understanding the LIR Infrared Spectrum of Bare CH_5^+, Science **309**, 1219-1222 (2005)
[5] O. Asvany, K.M.T. Yamada, S. Brünken, A. Potapov, S. Schlemmer, *Experimental Ground State Combination Differences of CH_5^+*, Science **347** (2015) 1346-1349